PLASMA ETCHING METHOD

BACKGROUND OF THE INVENTION

Technical Field

[**0001**] The present invention relates to a plasma etching method, and particularly to a plasma etching method for forming a trench satisfactorily.

Background Art

[**0002**] In recent years, with the miniaturization of electronic apparatuses, semiconductor devices corresponding to the apparatuses have also been required to be miniaturized. Therefore, with the aim of element separation of a semiconductor device and securing of a memory cell capacity area, a trench (ditch) and a via hole (hole), which are formed in a silicon substrate, are required to have a high aspect ratio (depth of the ditch or the hole / diameter of the ditch or the hole) that is, for example, equal to or more than 40. Moreover, as a method of forming a trench and a via hole having such a high aspect ratio, there is a plasma etching method by which, using activated species (ion and radical) generated by energizing etching gas into a plasma state, etching of a silicon substrate is performed. Plasma etching mechanisms for the trench and the via hole are almost the same, so the following description is given for the trench.

[**0003**] The trench is required to have a high aspect ratio, and is also required to have an angle of inclination of a side wall part as shown in FIG. 10 at about 90 degrees (vertical). However, when a trench having a high aspect ratio is to be realized, shape control of the trench becomes difficult, so that there is a problem that it is not possible to satisfy both of the requirement for the trench shape and the requirement for the aspect ratio. More specifically, in an

etching process of a silicon substrate by the plasma etching method, radicals which are electrically neutral isotropically enter a surface of the silicon substrate, and cause side etching, so that especially for a trench having a high aspect ratio, this side etching becomes significant, which results in the trench shape not being a predetermined shape but a shape as shown in FIG. 11.

[**0004**] As prior methods for solving such a problem, there are, for example, plasma etching methods described in patent documents 1 and 2.

[**0005**] The following describes etching of a silicon substrate by the plasma etching method described in patent documents 1 and 2, with reference to FIGS. 12A to 12D.

[**0006**] Firstly, as shown in FIG. 12A, using a mask 300 by which a pattern is formed, by activated species generated by energizing etching gas into a plasma state, etching of a silicon substrate 310 is performed. Here, ions are accelerated by a negative bias, vertically enter a surface of a silicon substrate 310, and etch in a vertical direction, while radicals isotropically enter the surface of the silicon substrate 310 and cause side etching below the mask 300 of an upper end aperture.

[**0007**] Next, as shown in FIG. 12B, a protection film 320 for etching is formed on a surface of the silicon substrate 310 in a trench.

[**0008**] Next, as shown in FIG. 12C, etching of the silicon substrate 310 is further performed by the activated species. Here, a trench sidewall is covered with the protection film 320, so that etching of the side surface by the radical is not progressed, but etching in a vertical direction and etching of a newly appeared trench side wall are progressed.

[**0009**] Next, as shown in FIG. 12D, the above processes of FIGS. 12A to 12C are repeated.

As described above, according to the conventional plasma etching method, the etching process is performed by being divided

into a plurality of times, and prior to progress of the etching, the trench sidewall is covered with the protection film. Thereby, by increasing the number of the etching, a trench having a high aspect ratio can be formed, and progress of the etching to the trench sidewall can be restrained, so that it is possible to satisfy both the requirement for the trench shape and the requirement for the aspect ratio.

Patent document 1: Japanese Patent Laid-Open No. 60-50923 publication

Patent document 2: Japanese Patent Laid-Open No. 7-503815 publication

BRIEF SUMMARY OF THE INVENTION

Problem to be Solved by the Invention

[**0010**] However, the conventional plasma etching method has a problem that the etching process and the process of the protection film forming are repeatedly performed, which results in causing unevenness of the trench side wall.

[**0011**] Accordingly, in view of the problem, an object of the present invention is to provide a plasma etching method which makes it possible to satisfy both the requirement for the trench shape and the requirement for the aspect ratio, and also possible to form a trench having a side wall of a smooth shape.

Means to Solve the Problem

[**0012**] In order to achieve the above object, a plasma etching method of performing plasma etching to an object made of silicon in a treatment chamber includes: introducing, into the treatment chamber, an etching gas which includes a fluorine compound gas and a rare gas; and etching the object by energizing the etching gas into a plasma state. Here, the etching gas may further include one of oxygen (O_2) gas, carbon monoxide (CO) gas, and carbon dioxide

(CO_2) gas, and the fluorine compound gas may be sulfur hexafluoride (SF_6) gas, the rare gas may be helium (He) gas, a volume of the helium (He) gas introduced into the treatment chamber may be equal to or more than 30% of a total flow rate of the etching gas, and the etching gas may be energized into a plasma state by an inductively coupled plasma (ICP) method.

[**0013**] By the above structures, it is possible to generate gas flow by which gas inside the trench is removed to the outside, and to shorten a stay time of reaction products and activated species inside the trench, so that even when a trench having a high aspect ratio is formed, it is possible to restrain situations where side etching occurs in the trench or where the trench tapers. This means that it is possible to realize a plasma etching method by which both the requirement for the trench shape and the requirement for the aspect ratio can be satisfied. Moreover, by a single etching process, a trench can be formed in the silicon substrate, which prevents occurrence of the unevenness of the trench side wall. This means that it is possible to realize a plasma etching method by which a trench having a side wall with a smooth shape can be formed.

[**0014**] Here, an inside wall of the treatment chamber may be made of an insulating material. Further, the insulating material may be one of quartz, alumina, an aluminum matrix with alumite treatments, yttrium oxide, silicon carbide, and aluminum nitride.

[**0015**] Thereby, a plasma density is kept high, and an etching rate is maintained high, so that it is possible to prevent reduction of a side wall protection effect for the trench, which makes it possible to realize a plasma etching method by which side etching does not occur in the trench and a trench of a predetermined shape can be formed.

[**0016**] Further, the etching gas may further include chlorine (Cl_2) gas. Further, a volume of the chlorine (Cl_2) gas introduced into the treatment chamber may be equal to or less than 10% of a total flow

rate of the etching gas.

[**0017**] Thereby, the etching gas includes Cl_2, so that in the case where the trench side wall protection effect is too strong, it is possible to realize a plasma etching method which can reduce a residual substance at the bottom of the trench which is caused when the protecting effect is achieved up to a bottom of the trench and the etching is partly inhibited.

[**0018**] Further, the fluorine compound gas may be one of sulfur hexafluoride (SF_6) gas and nitrogen trifluoride (NF_3) gas, and in the energizing into plasma state, electricity having a frequency that is equal to or more than 27 MHz may be supplied to the etching gas.

[**0019**] Thereby, progress of the side etching in the trench can be restrained, so that it is possible to realize a plasma etching method by which the side etching does not occur in the trench and a trench of a predetermined shape can be formed.

[**0020**] Further, the rare gas may be helium (He) gas, and a volume of the helium (He) gas introduced into the treatment chamber may be equal to or more than 80% of a total flow rate of the etching gas.

[**0021**] Thereby, the progress of the side etching in the trench can be further restrained, so that it is possible to realize a plasma etching method by which a trench of a predetermined shape can be formed.

[**0022**] Further, the etching gas further may include polymer forming gas, and the fluorine compound may be sulfur hexafluoride (SF_6) gas, and the polymer forming gas may be one of octafluorocyclobutane (C_4F_8) gas, trifluoromethane (CHF_3) gas, octafluorocyclopentene (C_5F_8) gas, and hexafluorobutadiene (C_4F_6) gas. Further, the fluorine compound gas may be sulfur hexafluoride (SF_6) gas, and in the energizing into a plasma state, electricity having a frequency of 500 kHz may be supplied to the etching gas.

[**0023**] Thereby, when the SOI substrate is etched, even after an

insulating stopper layer is exposed, the trench sidewall can be continued to be protected, so that it is possible to realize a plasma etching method by which side etching does not occur in a trench and a trench of a predetermined shape can be formed in a SOI substrate or the like.

[**0024**] Further, the plasma etching method according to the present invention may include etching the object by using an etching gas which includes one of oxygen (O_2) gas, carbon monoxide (CO) gas, and carbon dioxide (CO_2) gas, and uses sulfur hexafluoride (SF_6) gas as the fluorine compound gas; and then further etching the object by using etching gas which includes polymer forming gas and uses sulfur hexafluoride (SF_6) gas as the fluorine compound gas.

[**0025**] Thereby, it is possible that, until the insulating stopper layer is exposed due to etching, etching using the O_2 gas is performed to realize a high etching rate, and after the insulating stopper layer is exposed by the etching, etching using the polymer forming gas is performed to realize etching by which progress of side etching becomes small.

[**0026**] Further, the fluorine compound gas may be tetrafluoroethane (CF_4) gas. Further, the rare gas may be Ar gas, and a volume of the Ar gas introduced into the treatment chamber may be 50% to 90% of a total flow rate of the etching gas.

[**0027**] By these structures, reactivity can be reduced and the etching rate can be decreased, so that it is possible to form, with high accuracy, a shallow trench having a high aspect ratio.

Effect of the Invention

[**0028**] The plasma etching method according to the present invention can, even when a trench having a high aspect ratio is to be formed, restrain the situations where side etching occurs in the trench and where the trench tapers, so that both the requirement for the trench shape and the requirement for the aspect ratio can be

satisfied. Further, it is possible to form a trench having a side wall with a smooth shape. Still further, it is possible to prevent side etching from occurring in the trench and to form a trench of a predetermined shape. Still further, it is possible to form, with high accuracy, a shallow trench having a high aspect ratio.

[**0029**] Thus, according to the present invention, it is possible to provide a plasma etching method by which both of the requirement for the trench shape and the requirement for the aspect ratio can be satisfied, and a trench having a side wall of a smooth shape can be formed, so that the present invention is highly suitable for practical use.

Brief Description of Drawings

[**0030**] [FIG. 1] FIG. 1 is a diagram showing a structure of a plasma etching device of the first embodiment of the present invention.

[FIG. 2] FIG. 2 is a view for explaining an effect of using helium gas as an etching gas in the plasma etching device of the above embodiment.

[FIG. 3A] FIG. 3A is a view for explaining an effect of using an insulating material for an inside wall of an etching chamber, in the plasma etching device of the above embodiment.

[FIG. 3B] FIG. 3B is a view for explaining the effect of using the insulating material for the inside wall of the etching chamber, in the plasma etching device of the above embodiment.

[FIG. 4] FIG. 4 is a view showing a structure of a plasma etching device of the second embodiment of the present invention.

[FIG. 5] FIG. 5 is a graph showing a relationship between a volume of helium and a size of undercut.

[FIG. 6] FIG. 6 is a cross-sectional view of a SOI substrate in which a trench having a notch is formed.

[FIG. 7] FIG. 7 is a view showing a structure of a plasma etching device of the third embodiment of the present invention.

[FIG. 8] FIG. 8 is a view showing a structure of the plasma etching device of the fourth embodiment of the present invention.

[FIG. 9] FIG. 9 is a view for explaining how a trench is formed in a silicon substrate, in the plasma etching device of the above embodiment.

[FIG. 10] FIG. 10 is a cross-sectional view of a silicon substrate in which a trench of a predetermined shape is formed.

[FIG. 11] FIG. 11 is a cross-sectional view of a silicon substrate in which a trench in which side etching occurs is formed.

[FIG. 12A] FIG. 12A is a view for explaining etching of a silicon substrate using the conventional plasma etching method.

[FIG. 12B] FIG. 12B is a view for explaining the etching of the silicon substrate using the conventional plasma etching method.

[FIG. 12C] FIG. 12C is a view for explaining the etching of the silicon substrate using the conventional plasma etching method.

[FIG. 12D] FIG. 12D is a view for explaining the etching of the silicon substrate using the conventional plasma etching method.

Numerical References

[**0031**]

100, 1100	Etching chamber
110	Upper electrode
120	Lower electrode
130a, 130b, 730a, 730b, 1030a, 1030b, 1110a, 1110b	High frequency power supply
140, 1120	Gas introducing port
150, 1130	Exhaust port
300	Mask
310, 910, 1150a	Silicon substrate
320	Protection film
600	Etching chamber wall
610	Plasma
900	Notch

920	Stopper layer
1000	Undercut
1140	Dielectric coil
1150	Electrode
1150a	Silicon substrate
1160	Dielectric board
1170	Heater
1180	Chamber heater

DETAILED DESCRIPTION OF THE INVENTION

[**0032**] The following describes a plasma etching device according to embodiments of the present invention with reference to the drawings.

(First Embodiment)

FIG. 1 is a view showing a structure of a plasma etching device of the first embodiment.

[**0033**] The plasma etching device is, for example, an inductively coupled plasma (ICP) etching device, and includes: a vacuum etching chamber 100; an upper electrode 110 and a lower electrode 120 in the etching chamber 100; high frequency power supplies 130a and 130b; a gas introducing port 140; and an exhaust port 150.

[**0034**] The etching chamber 100 is a treatment chamber where etching is performed, and an inside wall thereof is made of, for example, quartz, alumina, an aluminum matrix with alumite treatment, an insulating material such as yttrium oxide, or the like.

[**0035**] The high frequency power supplies 130a and 130b supply high-frequency electricity having a frequency of 13.56 MHz, for example.

The gas introducing port 140 supplies gas into the etching chamber 100.

[**0036**] The exhaust port 150 exhausts gas which exists in the

etching chamber 100.

Next, a trench processing for a silicon substrate using the above-described plasma etching device, which is one process in manufacturing of a semiconductor device such as a transistor, is described sequentially herein below.

[**0037**] Firstly, a silicon substrate is placed on the lower electrode 120, and keeping a constant pressure in the etching chamber 100, etching gas is supplied into the etching chamber 100 through the gas introducing port 140 and exhausted from the exhaust port 150. Note that the etching gas is a mixed gas which mainly includes fluorine compound gas, for example sulfur hexafluoride (SF_6) gas, with added gas, for example oxygen (O_2) gas and a rare gas such as helium (He) gas. Note also that, regarding a volume of helium, if the volume is small, a ratio of the SF_6 gas and the O_2 gas in the etching gas becomes large which causes side etching in the trench or tapering of the trench, while if the volume is large, the ratio of the SF_6 gas and the O_2 gas in the etching gas becomes small which fails to make the etching progress, so that the volume of helium is adjusted to be equal to or more than 30% of a total flow rate. Note also that the added gas may be a carbon compound such as carbon monoxide (CO) or carbon dioxide (CO_2), and the rare gas may be argon (Ar) gas, xenon (Xe) gas, neon (Ne) gas, or krypton (Kr) gas.

[**0038**] Next, from the high frequency power supplies 130a and 130b, high-frequency electricity is supplied to the upper electrode 110 and the lower electrode 120, respectively, and the etching gas is energized into a plasma state. Activated species in the plasma, such as a fluorine F^+ ion and a fluorine (F) radical, are reacted with a silicon of the silicon substrate to generate reaction products, such as silicon tetrafluoride (SiF_4) and silicon dioxide (SiO_2), and etch the silicon substrate to form a trench. Here, in consideration that the object to be etched is a silicon substrate, radio frequency (RF) power supplied to the lower electrode 120 is set to low, for example, about

50 W.

[**0039**] As described above, the plasma etching device of the first embodiment can, using an etching gas including He gas, form a trench in the silicon substrate. Therefore, as shown in FIG. 2, it is possible to generate gas flow by which gas inside the trench is removed to the outside, and to shorten a stay time of the reaction products and the activated species inside the trench, so that even when a trench is to be formed to have a high aspect ratio that is, for example, equal to or more than 40, the plasma etching device of the first embodiment can restrain situations where side etching occurs in the trench or where the trench tapers. This means that it is possible to realize a plasma etching device which can satisfy both the requirement for the trench shape and the requirement for the aspect ratio.

[**0040**] Further, the plasma etching device of the first embodiment can, by performing the etching process once, form a trench in a silicon substrate. Thereby, it is possible to prevent occurrence of unevenness of the trench side wall, so that the plasma etching device of the first embodiment can be realized as a plasma etching device which can form a trench having a side wall with a smooth shape.

[**0041**] Still further, the plasma etching device of the first embodiment etches the silicon substrate, using an etching gas including O_2 gas. Thereby, a side wall protection effect for the trench can be increased, so that the plasma etching device of the first embodiment can be realized as a plasma etching device which can prevent side etching in the trench and can form a trench of a predetermined shape.

[**0042**] Still further, in the plasma etching device of the first embodiment, an inside wall of the etching chamber 100 is made of an insulating material. Thereby, as shown in FIG. 3A, due to collision of electrons generated by electric discharge on an etching

chamber wall 600, a density of plasma 610 does not become low, so that, as shown in FIG. 3B, it is possible to keep the plasma density high and maintains an etching rate high to prevent reduction of the side wall protection effect for the trench, which enables the plasma etching device of the first embodiment to be realized as a plasma etching device which can prevent side etching in the trench and can form a trench of a predetermined shape.

[**0043**] Note that, in the plasma etching device of the first embodiment, the etching gas is mixed gas which mainly includes SF_6 gas added with O_2 gas and a rare gas. However, in the etching gas, chlorine (Cl_2) gas, which is, for example, equal to or less than 10%, for example about 10%, of a total flow rate, may be further added. Thereby, in the case where the trench side wall protection effect is too strong, it is possible to reduce a residual substance at the bottom of the trench which is caused when the protecting effect is achieved up to a bottom of the trench and the etching is partly inhibited.

[**0044**] Note also that, in the plasma etching device of the first embodiment, the etching gas mainly includes SF_6 gas, but the etching gas may mainly include nitrogen trifluoride (NF_3) gas.

[**0045**] (Second Embodiment)

In the above-described plasma etching device of the first embodiment, as an etching gas, the mixed gas which includes SF_6 gas, O_2 gas, and a rare gas is used, and the mixed gas is applied with electricity having a high frequency of 13.56 MHz, for example. However, if, as etching gas, mixed gas which does not include O_2 gas, namely, mixed gas which includes fluorine compound gas such as SF_6 gas, and a rare gas, is used, and the mixed gas is applied with electricity having a high frequency that is equal to or more than 27 MHz, the same effect as described above can be obtained.

[**0046**] Therefore, in a plasma etching device of the second embodiment, as an etching gas, a mixed gas which includes fluorine

compound gas, such as SF_6 gas, and a rare gas, is used, and the mixed gas is applied with electricity having a high frequency that is equal to or more than 27 MHz. The following describes mainly features that are different from the features of the first embodiment.

[**0047**] FIG. 4 is a view showing a structure of the plasma etching device of the second embodiment.

The plasma etching device has high frequency power supplies which are different from the high frequency powers of the plasma etching device of the first embodiment, and includes the etching chamber 100, the upper electrode 110 and the lower electrode 120, high frequency powers 730a and 730b, the gas introducing port 140, and the exhaust port 150.

[**0048**] The high frequency power supplies 730a and 730b supply high-frequency electricity having a frequency that is equal to or more than 27 MHz, for example, high-frequency electricity having a frequency of 27 MHz with low electric power consumption.

[**0049**] Next, a trench processing for a silicon substrate using the above-described plasma etching device is described sequentially herein below.

[**0050**] Firstly, a silicon substrate is placed on the lower electrode 120, and keeping a constant pressure in the etching chamber 100, etching gas is supplied to the etching chamber 100 through the gas introducing port 140 and exhausted from the exhaust port 150. Note that the etching gas is a mixed gas which mainly includes a fluorine compound gas, such as SF_6 gas, added with a rare gas such as He gas. Note also that a degree of progress of side etching in the trench, in other words, a size of undercut (1000 in FIG. 11) has variations as shown in FIG. 5 corresponding to a volume of helium. More specifically, the degree of progress of side etching is increased when the volume of helium becomes less than 80%. Therefore, the volume of helium is adjusted to be equal to or more than 80% of a

total flow rate. Note also that the rare gas may be Ar gas or Xe gas.

[**0051**] Next, from the high frequency power supply 730a and 730b, high-frequency electricity is supplied to the upper electrode 110 and the lower electrode 120, respectively, and the etching gas is energized into a plasma state. Activated species in the plasma, such as a F^+ ion and a F radical, are reacted with a silicon of the silicon substrate to generate reaction products, such as SiF_4, and etch the silicon substrate to form a trench.

[**0052**] As described above, the plasma etching device of the second embodiment, as well as the plasma etching device of the first embodiment, can be realized as a plasma etching device which can satisfy both the requirement for the trench shape and the requirement for the aspect ratio.

[**0053**] Further, the plasma etching device of the second embodiment, as well as the plasma etching device of the first embodiment, can be realized as a plasma etching device which can form a trench having a side wall with a smooth shape.

[**0054**] Still further, in the plasma etching device of the second embodiment, the etching gas is applied with electricity having a high frequency that is equal to or more than 27 MHz in order to energize the etching gas into a plasma state, thereby etching the silicon substrate. Thereby, side etching in the trench can be restrained, so that the plasma etching device of the second embodiment can be realized as a plasma etching device which can prevent side etching in the trench and can form a trench of a predetermined shape.

[**0055**] Note that, in the plasma etching device of the second embodiment, the etching gas mainly includes SF_6 gas, but the etching gas may mainly include NF_3 gas.

[**0056**] Note also that, in the plasma etching device of the second embodiment, if, as the etching gas, a mixed gas, which includes SF_6 gas, O_2 gas, and a rare gas, is used, and the mixed gas is applied with electricity having a high frequency that is equal to or more than

27 MHz, the same effect as described above can be obtained.

(Third Embodiment)

[**0057**] In the above-described plasma etching device of the first embodiment, as the etching gas, the mixed gas which includes SF_6 gas, O_2 gas, and a rare gas is used. However, if, as the etching gas, a mixed gas, which includes a fluorine compound gas such as SF_6 gas, a polymer forming gas, and a rare gas, is used, the same effect as described above can be obtained, and furthermore, the progress of side etching can be restrained, when the etching is performed for a silicon substrate, such as a silicon-on-insulator (SOI) substrate, below which an insulating stopper layer is formed.

[**0058**] More specifically, the plasma etching device of the first embodiment protects the trench side wall by the reaction products which are generated when oxygen is reacted with silicon. Thereby, when in the SOI substrate or the like, a stopper layer is exposed due to the etching, the generation of the reaction products is stopped and eventually the trench sidewall cannot be protected, so that a notch 900 as shown in FIG. 6 is formed in a silicon substrate 910 adjacent to the stopper layer 920. However, if a polymer forming gas is used as the etching gas, the trench sidewall is protected by polymers formed by the polymer forming gas. Therefore, even if the stopper layer is exposed, the forming of the polymers is not stopped, so that it is possible to continue to protect the trench side wall.

[**0059**] Thus, in the plasma etching device of the third embodiment, as the etching gas, a mixed gas, which includes fluorine compound gas such as SF_6 gas, the polymer forming gas, and a rare gas, is used. The following describes mainly features that are different from the features of the first embodiment. Note that, examples of the polymer forming gas are octafluorocyclobutane (C_4F_8) gas, trifluoromethane (CHF_3) gas, octafluorocyclopentene (C_5F_8) gas, hexafluorobutadiene (C_4F_6) gas, and the like.

[**0060**] FIG. 7 is a view showing a structure of the plasma etching device of the third embodiment.

The plasma etching device has the basically same structure as the plasma etching device of the first embodiment, and includes the etching chamber 100, the upper electrode 110 and the lower electrode 120, high frequency power supplies 1030a and 1030b, the gas introducing port 140, and the exhaust port 150.

[**0061**] Next, a trench processing for a SOI substrate using the above-described plasma etching device is described sequentially herein below.

[**0062**] Firstly, a SOI substrate is placed on the lower electrode 120, and keeping a constant pressure in the etching chamber 100, etching gas is supplied to the etching chamber 100 through the gas introducing port 140 and exhausted from the exhaust port 150. Note that the etching gas is a mixed gas which mainly includes a fluorine compound gas, such as SF_6 gas, added with a polymer forming gas, a rare gas such as He gas. Note also that, regarding a volume of helium, if the volume is small, a ratio of the SF_6 gas in the etching gas becomes large which causes side etching in the trench or tapering of the trench, while if the volume is large, the ratio of the SF_6 gas in the etching gas becomes small which fails to make the etching progress, so that the volume of helium is adjusted to be equal to or more than 30% of a total flow rate. Note also that the rare gas may be Ar gas or Xe gas.

[**0063**] Next, from the high frequency power supplies 1030a and 1030b, high-frequency electricity is supplied to the upper electrode 110 and the lower electrode 120, respectively, and the etching gas is energized into a plasma state. Activated species in the plasma, such as a F^+ ion and a F radical, are reacted with a silicon of the SOI substrate to generate reaction products, such as hexafluorodisilane (Si_2F_6), and etch a silicon substrate, which is the SOI substrate, until the stopper layer is exposed, and to form a trench.

[**0064**] As described above, the plasma etching device of the third embodiment, as well as the plasma etching device of the first embodiment, can be realized as a plasma etching device which can satisfy both the requirement for the trench shape and the requirement for the aspect ratio.

[**0065**] Further, the plasma etching device of the third embodiment, as well as the plasma etching device of the first embodiment, can be realized as a plasma etching device which can form a trench having a side wall with a smooth shape.

[**0066**] Still further, the plasma etching device of the third embodiment forms a trench in the SOI substrate, using the etching gas which includes the polymer forming gas. Thereby, even after the stopper layer is exposed, it is possible to continue to protect the trench side wall, so that the plasma etching device of the third embodiment can be realized as a plasma etching device which can prevent side etching in the trench and can form a trench of a predetermined shape in a SOI substrate or the like.

[**0067**] Note that it has been described, in the plasma etching device of the third embodiment, that by using, as the etching gas, the mixed gas including SF_6 gas, a polymer forming gas, and a rare gas, the progress of side etching is restrained, when the etching is performed on a silicon substrate, such as the SOI substrate, below which a stopper layer below is formed. However, even if, as the etching gas, a mixed gas which does not include the polymer forming gas, namely, a mixed gas which includes a fluorine compound gas such as SF_6 gas, and a rare gas, is used, when the plasma etching device has a low frequency power supply which supplies low-frequency electricity having a frequency of 500 kHz, for example, and supplies the low-frequency electricity having a frequency of 500 kHz to the etching gas, the same effect as described above can be obtained.

[**0068**] More specifically, in the plasma etching device of the first

embodiment, the high-frequency electricity having a frequency of 13.56 MHz is used, so that positive ions enter the silicon substrate at a slow speed. Therefore, when in the SOI substrates the stopper layer is exposed due to the etching, by the stopper layer charged with the positive ions which have already entered, a track of a positive ion which subsequently enters is changed. However, when electricity having a low frequency of 500 kHz is used, the positive ion enters the silicon substrate at a high speed. Therefore, even if in a SOI substrate or the like, the stopper layer is exposed due to the etching, the track of a positive ion is not significantly changed, so that it is possible to continue to protect the trench side wall.

[**0069**] Therefore, by supplying electricity having a low frequency of 500 kHz to the etching gas in order to energize the etching gas into a plasma state, it is possible to realize a plasma etching device which can form a trench of a predetermined shape in a SOI substrate or the like.

[**0070**] Note that it has been described that the plasma etching device of the third embodiment can be realized as a plasma etching device which can form a trench of a predetermined shape in a SOI substrate or the like, by the above-described etching using the polymer forming gas or the etching using the electricity having a low frequency. However, it is also possible that, until the trench processing is progressed 50% to 90%, for example, etching is performed as described in the first embodiment using, as etching gas, the mixed gas including SF_6 gas, O_2 gas, and a rare gas, and after that, for the remaining trench processing, the above etching described in the third embodiment is performed using the polymer forming gas or using electricity having a low frequency.

[**0071**] Thereby, it is possible that, until the insulating stopper layer is exposed by etching, etching using the O_2 gas is performed to realize a high etching rate, and after the stopper layer is exposed by the etching, etching using the polymer forming gas is performed to

realize etching by which the progress of side etching becomes small.

[**0072**] Note also that, in the plasma etching device of the third embodiment, the etching gas mainly includes SF_6 gas, but the etching gas may mainly include nitrogen trifluoride (NF_3) gas.

[**0073**] (Fourth Embodiment)

In the above-described plasma etching device of the first embodiment, immediately after starting the etching processing, the trench processing is finished before the plasma is stabilized, which causes variations of depth of the trench. Therefore, when a trench is to be formed to have a shallow depth that is, for example, equal to or less than 200 nm, it is necessary to lower an etching rate in order not to let the trench processing be finished before the plasma is stabilized. However, in the plasma etching device of the first embodiment, the etching rate cannot be lower than 50 nm/min, so that when a trench having a shallow depth is to be formed, the trench processing is finished before the plasma is stabilized, which fails to form, with high dimension accuracy, a trench having a shallow depth. Here, as a method of lowering the etching rate, a method of reducing the RF power supplied to the lower electrode can be conceived, but when the RF power is reduced, the plasma density becomes low, thereby making it difficult to obtain a desired radical ion and causing instability of electric discharge, so that this method causes a new problem.

[**0074**] Therefore, in the plasma etching device of the fourth embodiment, as the etching gas, a mixed gas, which includes a fluorine compound gas such as SF_4 gas, and a rare gas, is used. The following describes mainly features that are different from the features of the first embodiment.

[**0075**] FIG. 8 is a view showing a structure of the plasma etching device of the fourth embodiment.

The plasma etching device is, for example, an ICP etching device, and includes: a vacuum etching chamber 1100; high

frequency power supplies 1110a and 1110b; a gas introducing port 1120; an exhaust port 1130; a dielectric coil 1140 of a spiral antenna shape; an electrode 1150 on which a silicon substrate 1150a is placed; a dielectric board 1160 such as a quartz plate; a heater 1170; and a chamber heater 1180.

[**0076**] The etching chamber 1100 is a treatment chamber where etching is performed,

The high frequency power supplies 1110a and 1110b supply high-frequency electricity having a frequency of, for example, 13.56 MHz, to the dielectric coil 1140 and the electrode 1150.

[**0077**] The gas introducing port 1120 supplies gas into the etching chamber 1100.

The exhaust port 1130 exhausts gas which exists in the etching chamber 1100.

[**0078**] Next, a trench processing for a silicon substrate using the above-described plasma etching device is described sequentially herein below.

[**0079**] Firstly, on the lower electrode 1150 the silicon substrate 1150a is placed, and in keeping a constant pressure in the etching chamber 1100, etching gas is supplied to the etching chamber 1100 through the gas introducing port 1120 and exhausted from the exhaust port 1130. Note that the etching gas is mixed gas which mainly includes fluorine compound gas, such as tetrafluoroethane (CF_4) gas, added with rare gas such as Ar gas. Note also that, regarding a volume of argon, if the volume is small, a ratio of the CF_4 gas in the etching gas becomes large which causes side etching in the trench or tapering of the trench, while if the volume is large, the ratio of the CF_4 gas in the etching gas becomes small which fails to make the etching progress, so that the volume of argon is adjusted to be 50% to 90% of a total flow rate. Note also that the rare gas may be He gas, or Xe gas.

[**0080**] Next, from the high frequency power supplies 1110a and

1110b, high-frequency electricity is supplied to the dielectric coil 1140 and the electrode 1150, respectively, and the etching gas is energized into a plasma state. As shown in FIG. 9, activated species in the plasma, such as a F^+ ion and a F radical, are reacted with a silicon of the silicon substrate to generate reaction products, such as SiF_X and Si_2F_6, and etch the silicon substrate to form a trench.

[**0081**] As described above, the plasma etching device of the fourth embodiment can form a trench in a silicon substrate, using a etching gas including Ar gas. Therefore, it is possible to generate gas flow by which gas inside the trench is removed to the outside, and to shorten a stay time of the reaction products and the activated species inside the trench, so that even when a trench is to be formed to have a high aspect ratio that is, for example, equal to or more than 40, the plasma etching device of the fourth embodiment can restrain situations where side etching occurs in the trench or where the trench tapers. This means that it is possible to realize a plasma etching device which can satisfy both the requirement for the trench shape and the requirement for the aspect ratio.

[**0082**] Further, the plasma etching device of the fourth embodiment can form a trench in a silicon substrate, by performing the etching process once. Thereby, it is possible to prevent occurrence of unevenness of the trench side wall, so that the plasma etching device of the fourth embodiment can be realized as a plasma etching device which can form a trench having a side wall with a smooth shape.

[**0083**] Still further, the plasma etching device of the fourth embodiment forms the trench in the silicon substrate, using, as the etching gas, the mixed gas which mainly includes CF_4 gas whose degree of dissociating the radical is smaller as compared to SF_6 gas, and is added with Ar gas. Thereby, reactivity can be reduced, and the etching rate can be lower than 50 nm/min, for example, 12

nm/min, so that the plasma etching device of the fourth embodiment can be realized as a plasma etching device which can form, with high accuracy, a trench which has a shallow depth that is equal to or less than 200 nm and has a high aspect ratio. More specifically, when a trench having a depth of 100 nm is to be formed at an etching rate of 2000 nm/min, etching completes within about three seconds, so that in consideration that a time required until the plasma stabilization varies within about one second depending on smaples, the etching depth varies about 30%, which exceeds about 5% that is allowed for the depth variations, but when the trench having a depth of 100 nm is to be formed at an etching rate of 20 nm/min, the etching depth varies about 0.3% using the same calculation, which does not exceed about 5%, so that the plasma etching device of the fourth embodiment can control the etching in a depth direction with significantly high accuracy.

Industrial Applicability

[**0084**] The present invention can be applied to a plasma etching method, and particularly to etching of a semiconductor substrate during trench processing of the semiconductor device, and the like.